MODELLING OF MATERIAL REMOVAL RATE ON GRINDING DUCTILE IRON USING WATER BASED SiO_2 NANOCOOLANT

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ABSTRACT

This project presents the modelling of the material removal rate on grinding ductile iron using water based silicon dioxide (SiO_2) nanocoolant using response surface method. The grinding fluids used in this study are conventional coolant and water based SiO2 nanoparticle grinding fluid. The SiO_2 nanocoolant is prepared using two step methods. The design of experiment for the grinding process is developed using central composite design method. The method of grinding process is single pass and multiple pass. For the experiment, the parameter has been considered as speed of table and depth of cut. The range of the speed of table is 20-40 m/min and the depth of cut is 20-60 µm. The surface roughness, G-ratio, temperature different, and also material removal rate are selected as the output parameters. The use of central composite design method is use to obtained the prediction model for material removal rate. The analysis of variance has been performed to check the adequacy of the develop mathematical model. It can be seen that the lack of fit for all models are less than 0.005 and R-square value for all model are more than 90 %. Therefore, the mathematical models for conventional and SiO_2 nanocoolant with single and multiple pass grinding acceptable. The obtained results show the better medium for grinding fluid are the conventional grinding in terms of material removal rate however, the surface roughness for conventional coolant is poor compared to the SiO_2 nanocoolant.

ABSTRACK

Projek ini adalah mengenai membina model untuk Material Removal Rate dengan mencanai ductile iron menggunakan water based silicon dioxide (SiO_2) nanocoolant dan menggunakan response surface method. Coolant yang digunakan dalam kajian ini adalah coolant dari jenis konvensional dan water based silicon dioxide (SiO_2) nanocoolant yang dihasilkan melalui kaedah two step methods. Reka bentuk eksperimen untuk proses mencanai adalah dihasilkan dengan menggunakan central composite design method. Kaedah mencanai yang digunakan adalah dari jenis single pass dan multiple pass. Untuk eksperimen, parameter yang digunakan adalah kelajuan meja mesin mencanai dan kedalaman potongan bahan. Julat untuk kelajuan meja mesin mencanai adalah antara 20-40 m/min dan untuk kedalaman potongan bahan adalah 20-60 µm. Surface roughness, G-ratio, perbezaan suhu bahan, dan material removal rate adalah parameter yang dipilih sebagai output. Penggunaan central composite design method adalanh untuk mendapatkan model jangkaan bagi parameter material removal rate. Analis untuk variance telah dibuat bagi mengesahkan kejituan model matematik yang dihasilkan. Ianya boleh dilihat melalui nilai lack of fit untuk model-model adalah kurang daripada 0.005 dan nilai R-square untuk semua nilai model adalah lebih daripada 90 %. Dengan itu, model matematik untuk konvensional dan SiO_2 nanocoolant untuk proses mencanai single dan multiple pass adalah diterima pakai. Hasil dari keputusan eksperimen, menunjukkan bahawa kesan untuk material removal rate bagi bahan adalah lebih baik menggunakan konvensional grinding fluid, tetapi bagi kesan surface roughness, penggunaan grinding fluid konvensional adalah kurang memuaskan berbanding SiO_2 nanocoolant.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Metalworking is divided by two operations that are metal forming and metal removing. Material removal process is among the most important manufacturing operations. This operation is widely used in order to design or create the metal based on specifications of the drawing, and this is strictly needed to be very precise. The removal process is generally divided into two categories that are metal cutting (chip generation) involving cutting on lathe, milling, planing, shaping, broaching, reaming, sawing, drilling, grinding, and others. Second is alternative material removal process utilizing electrical, chemical, optical (laser), and thermal technique. During machining process, friction between workpiece-cutting tool and cutting tool-chip interfaces cause high temperature on cutting tool. The effect of the high temperature decreases tool life, increases surface roughness and decreases the dimensional sensitiveness of work material (Cakir et al., 2007). This phenomenon is one of the problems when dealing with grinding process. The increasing of heat on the workpiece will cause more damages on it physical and also its microstructure properties. The thermal expansion that causes by the residue tensile stress on the workpiece is beyond the yield stress. It will give a result in material close to the surface that is under constant tension. The challenge is to get the high quality of surface finish, accuracy in dimensional, high production rate and fewer damages to the tool (Thamizhmanii and Hasan, 2006).

In contrast of metal cutting, grinding process require higher speed, smaller volumes of material removed per unit time, and the desire for improve surface finish and dimensional control. This requirement is very crucial in order to get the finest surface finish for some metal removing process. Therefore, for better performance of grinding process, there are something need to deal with is. The grinding process is performing at high speed, this makes the material become very hot in a very short time. In this problem, the solutions need to be done. The use of lubrication process is the ultimate solution. Lubricating is the important part of metal forming process. The process of grinding required the surface contact between tools and the work piece. This process generates a new surface and hence the tool-chips and tool-work piece interfaces are more critical. The new surface that been generated by grinding process are basically do not have the protection surface layers, such as oxides, lubricants, and contaminants, that are present on the work piece in forming operations. Thus, the proper lubricating method is needed to be done in order to overcome the problem when dealing high friction, elevated temperature and also the wear. This is very important to get a finest surface finish from grinding operations. The benefit that can get when using the various type of grinding fluid is such as longer tool life, and better dimensional accuracy. These results also offer higher cutting speeds, feed rates and depths of cut (Cakir et al., 2007).

To improve the use of lubrication process, nanotechnologies are the best way to deals with it. Nanofluid is the advanced product for lubricating fluids. The term ‘Nano’ describes the process of reducing the conventional material to the nanoscale that will be the effect on the fundamental physical and chemical properties to the great extent. Nanomaterial is prepared atom by atom or molecule by molecule to produce functionalized better material with distinctly unique properties. These nanotechnologies are involved to work at the molecular level in order to create a larger structure with fundamentally new arrangements. The good thing of nanotechnologies is the accuracy of placement, measurement, manipulation, and modelling of the matter in the range of 0.1 to 100 nanometres. When dealing in this range, the classic laws of physics are change and the production of new structure of materials with new properties becomes possible.

1.2 PROBLEM STATEMENT

Grinding process is one of the material removal process that is widely used in industry. This process is been the practice in order to get better surface quality and also very near tolerance that is very strict for design components. Since there is no other suitable way to do this task, grinding process are been chosen. When there is about grinding, the term thermal or high temperature will be heard. This is because this operation deals with high speed cutting tools that are abrasive wheel. When the tools are making contact with the workpiece surface, the heat rises in the second. In grinding process, it is involved with several parameters and this project will cover the depth of cut, speed of wheel and the feed rate. This is all the parameter that will be manipulated to have such a result. Coolant is used to enhance the performance of grinding in giving the better surface finish, reduce the temperature between the surface contacts and also can clean the surface from the chip generations during grinding process. Although the coolant gives solutions to the grinding process problem, still the performance is not good enough. The introduction of nanocoolant of the new coolant to replace the conventional coolant in order to overcome the temperature and surface finish problem. In this project, the investigate differentiation between the conventional coolant and nanocoolant in terms of material removal rate (MRR), and G-ratio.

1.3 PROJECT OBJECTIVES

The objectives of this project are as following:

1) To investigate the performance of grinding of ductile iron based on design of experiment
2) To develop prediction model for material removal rate using central composite design method.

1.4 SCOPE OF PROJECT

The scopes of this project are to construct the design of an experiment of material removal rate and also the preparations of SiO_2 Nanocoolant. In this research also perform the experiment on grinding machine utilizing abrasive grinding wheel using water based SiO_2 nanocoolant. Mathematical modelling for MRR and G-ratio analysis will also be discussed in this research, and all the data will be statically analyze using the central composite method.

1.5 OVERVIEW OF THE REPORT

There are all five chapters in this report. Chapter 1 is the introduction of this report. Chapter 2 provides more information about previous study that gives an evident that this research is possible to carry on. Chapter 3 presents the methodology of this research. All the machining process, the material involved and the equipment to run this research are discussed details in this chapter. Chapter 4 presents the important finding and their discussion. Chapter 5 is summarized the finding and proposed recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

From the beginning of this project, various literature studies have been done. The previous study about grinding, the use of nanocoolant and the evidence that show this research is possible to be run. Many of the research mention of the heat problem, and one of the solutions is using nanocoolant because it has a thermal conductivity effect much higher than conventional coolant. In material removal operations, the role of grinding process is vital. This process that contains the used of the abrasive wheel in order to design the material is an example one of the oldest processes of manufacturing. In terms of machining operations expenditure in industrialized countries, its account for nearly 20-25% of the total and it is more costly than other material removal processes. Grinding process is the abrasive material process that extensively been practise in manufacturing industries for finishing operations that demand fine surface finish and close tolerances. In grinding process, mostly the mechanical energy is turned into heat. At very high-temperature, the heat can cause thermal and mechanical damages to the workpiece. It affects the workpiece surface quality and process productivity. Therefore, this is one of the factors that need to be overcome in operational of grinding process. The amount of heat that enters the workpiece is important because it impacts the quality of the finished part. High temperature can lead to workpiece burn, thermal softening, and dimensional distortion (Chen et al., 1999)

2.2 GRINDING PROCESSES

Grinding is very complicated, which involved many parameters that included such as wheel speed, depth of cut, work speed, density and, etc. Since the goal is to get the fine surface finish and also the very near tolerance, grinding process need to be a study for better performance. The low speed of grinding can waste the abrasive wheel, but the high speed cause a hard grinding action and glaze the wheel. It can make the grinding process is inefficient (U.S Army, 1996). It introduces a nanocoolant as a new medium for the choice of coolant for a grinding process. In order to meet standard high surface finish, narrow tolerance and actually, the total overall process of grinding performance by controlling heat and wheel wear, a heavy supply of conventional fluids is used and for these situations, the nanocoolant are been chosen. Coolant flow, coolant pressure, tank size, and filtration are among the most important issues regarding optimization of your grinding system. First, the coolant flow should, in almost all cases, exceed the velocity of the wheel (Dale Savington, 2000). Heavy usage of lubricants is not guaranteed to enhance the lubrication action, but the effectiveness of the lubricating performance is depending on the fluid actually entering the arc contact. In addition, coolant keeps the chips washed away from the grinding wheel and point of contact, thus permitting free cutting (U.S Army, 1996). Figure 2.1 shows the different types of grinding processes.

(a) Horizontal Grinding

(b) Centreless Grinding

Figure 2.1: Types of grinding processes

Source: Colton (2009)

In conventional grinding process, there are three significant components that need to be awarded. During grinding, high friction generated by the sliding action of abrasive grains over the workpiece surface is converted into heat, causing the high temperature particularly at wheel-workpiece contact zone. The three components are abrasive wheel, grinding fluids and the limitations of conventional grinding process. Such elevated temperature at the interface can cause thermal damage to the workpiece, which affects its surface quality and limits the process efficiency. Abrasive wheel, the grinding process tools and grinding fluid are two most important part of the process. In grinding process, the cutting tools that used in this process are bonded abrasive wheel. The bonded wheel is made from a matrix of tiny and coarse abrasive particle called grains/grit pressed and bonded together with the bonding agent to form a solid, circular shape. A grinding wheel surface consists of numerous cutting edges or a sharp grit which means to remove the material from the workpiece surface.

This property of grinding wheel makes the process a multi point cutting tool operations. The grinding wheel is also characterized by its blunt edges on the surface and microscopic between the grits. The bonding matrix in which the abrasive grains are fixed may include a variety of organic materials such as rubber, shellac or resin; inorganic materials such as clay are also used. Inorganic bonds with glass-like or vitreous structures are used on the tool-sharpening wheels for the home workshop grinder, while resin bonds are used in masonry or steel-cutting wheels. Generally, vitrified bonds are used with medium to fine grain sizes in wheels needed for precision work. Resin bonds are used generally with coarse grains and for heavy-metal removal operations such as foundry work. In addition to their abrasive and bonding materials, grinding wheels often contain additional ingredients that produce pores within the wheel or assists chemically when a particular abrasive is used to grind a special material. One important aspect of a grinding wheel that can be created or altered through additives is porosity, which also contributes to the cutting characteristics of the grinding wheel. Porosity refers to the open spaces within the bond that allow room for small chips of metal, and abrasive generated during the grinding process. Porosity also provides pathways that carry fluids used to control heat and improve the cutting characteristics of the abrasive grains. Without adequate porosity and spacing between abrasive grains, the wheel can become loaded with chips and cease to cut properly.

In grinding process of the abrasive material removal process, the grinding fluids serve to the following important functions. The grinding fluid does give a lubrication action for the process. The fluid gives the area of contact with the grinding that is between the grinding wheel and the surface of the workpiece less in sliding friction between them. The grinding fluid also gives the cooling effect for the area of contact of the grinding process. This is very important to give the surface of workpiece a low-temperature experience which is exposing with high temperature will give certain damage to the workpiece surface. In addition, the flow of the grinding fluid will flush away the remaining chip on the surface that can affect the performance of grinding process. When the lubricating action is done, the effectiveness of this method can reduce the sliding frictions and wear by performing low shear strength-transfer film between the rubbing surfaces. The application of lubricating only took a part if only the fluids actually entering the arc of contact between the grinding wheel and workpiece. The capability of the fluids to remove or flush away the chip is depended on the flow speed and quantity of the fluid applied. The lubricating additives should have been capable of overcoating the swarf to avoid the workpiece surface from damages.

The supply of coolant to the grinding wheel is vital to the grinding process. The coolant helps keep the work piece and grinding wheel cool so the material being machined is not burned. In addition, the coolant transfers away the swarf material, keeping it from fouling the wheel. In order to make the lubrication performance is just as right to keep the material from any damages from heat or surface on its surface, the right amount of fluids needs to be control or the lubricating will give a bigger impact on grinding process. The better performance of grinding process is archived with the use of lubricants/fluids. The additional of using the nanoparticles/nanofluids will give the bigger impact. The transition from microparticles to nanoparticles can lead to a number of changes in physical properties. Two of the major factors in this is the increase in the ratio of surface area to volume, and the size of the particle moving into the realm where quantum effects predominate. The use of nanofluids as lubricating medium for grinding process is the better solution to improve the surface finish and also the near tolerance of the material.

2.3 NANOCOOLANT

The three limitations give an impact for two major problems that is the quality of the finish workpiece and the cost to produce a workpiece. The quality of the workpiece can be control by the usage of coolant. In order to improve the performance of coolant, the introducing of nanocoolant/nanofluids is the best solutions. Nanofluids are solid-liquid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 1 to 100 nm suspended in liquid. The performance of the coolant to give a reduction of heat on the workpiece is concerned with the properties of its heat transfer's capability. The high value of heat transfer properties can lead to better performance of coolant.

The coolant needs to have a capability to reduce the temperature that exists between the grinding tools and the workpiece. In grinding process, when the workpiece surface been cut by the tools, the new surface will be existed, if the that surface not treat well such as to control the temperature rising on it, it will make the surface burn that it the surface will be gone to be damages, and the fine surface finish will not be achieved. The surface of the workpiece also tends to crack if the surface gets to overload value of temperature. The grinding process generates an extremely high input of energy per unit volume of material removed.

Virtually, all this energy is converted to heat, which can cause high temperatures and thermal damage to the workpiece such as workpiece burn, phase transformations, undesirable residual tensile stresses, cracks, reduced fatigue strength, and thermal distortion and inaccuracies. All this damage affected the surface finish of the workpiece. The better used of coolant when the coolants are fully coated the surface of the workpiece which mean can cover the new layer of surface and also wash away the chips generated by the grinding of the surface to give the tool a better performance to make a clean cut. The introducing of nanoparticles in this case is very important. The use of solid particles as an additive suspended within the base fluid is the technique for the heat-transfer enhancement. Improving the thermal conductivity is the key idea to improve the heat-transfer characteristics of conventional fluids (Sridhara and Satapathy, 2011). The additions of solid particle as catalyze to perform better thermal conductivity through the coolant.

Since the solid is known to be more conductive to heat than the liquid, it was very significant that the solution of coolant with solid particle based will give better performance of reducing the temperature of material that been grinded. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter- or micrometer- sized particles has been well-known for many years (Sridhara and Satapathy, 2011). This is the first step to make the conventional coolant to a new improvisation. The addition of micrometer- or millimeter-sized solid metal or metal oxide particles to the base fluids shows an increment in the thermal conductivity of resultant fluids. But the presence of milli- or microsized particles in a fluid poses a number of problems. They do not form a stable solution and tend to settle down (Oronzio et al., 2010). So, the additional of solid particle eventually solved the heat-transfer problem but come with a new problem. However, they have not been of interest for practical applications due to problems such as sedimentation leading to increased pressure drop in the flow channel (Sridhara and Satapathy, 2011).

This is the right time to introduce what they said coolant with nanosizes or nanocoolants/nanoparticles. Nanofluids are solid-liquid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 1 to 100 nm suspended in liquid (Sridhara and Satapathy, 2011). Several investigations have revealed that the thermal conductivity of the fluid containing nanoparticles could be increased by more than 20% for the case of very low nanoparticles concentrations (Oronzio et al., 2010). Based on the earlier study about nanoparticles, it has shown that these elements can give the significant impact on conductive the heat and since the size is reduced to nanosizes, the problems such as the pressure drop in the flow channel can be reduced. There is an evident to the previous study that the usage of nanocoolant gives the better performance in case of thermal conductivity. The nanocoolant itself has higher the value of thermal conductivity.

The silicon dioxide or can be called as silica is the chemical compound with the chemical formula of SiO_2. The hardness of this compound is already known since the ancient times. This compound is commonly found in nature as sand and quartz. The primary use of silica is in production of glasses, and the majority of optical fibers are also using silica as the main component. Silica also used as the additive for the food product. The purpose of using this is to water in hygroscopic applications and also as the flow agent in powdered foods. The thermal conductivity is the main purpose to use the silica as the nanoparticles to dissolve in water. These properties will give the effect that increases the ability of the fluid to absorb the heat from the workpiece while in grinding process. The heat that has been absorbed will reduce the possibility of the workpiece to burn from high temperature and give fewer defects from excessive heat.

2.4 RESPONSE SURFACE METHOD

Generally, the is the interest of response variable that can be denoted by y with the set of the predictor variables like x_1, x_2 and so on. This is what been faced by many researcher with their experimental desire. Such example in dynamic network analysis (DNA), response surface methodology (RSM) can be useful for sensitivity of various DNA measures for the different type of random graphs and errors (Carley et al ., 2004). There is the basic correspond with that need to use from certain experimental research that is statistical experimental design fundamentals, regression modeling and also optimization methods. This requirement is always used to identify and fitting from experimental data for response surface methodology. RSM is actually the technique that for developing, improving and optimizing the process by some of the statistical data collection.

In this report, the main objective to use the RSM is to get the performance measure for the interest response that is material removal rate (MRR) of the surface of the material. The material will go under several sets of grinding process techniques. There will be some input that will influence the interest response that is speed of table of grinding machine and also the depth of cut (DOC) for grinding feed. These two variables will use in order to model the experimental design and also to get the prediction equation for the MRR.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter gives the method use to conduct the experiment based on this research. Start with the preparations of workpeice materials and also nanocoolant, this procedure is the guidelines on doing all the actions for running the experiments. The parameter selection for this experiment is based on the literature study from passed research and the output of this experiment is according to the objective and scope of this research. The machine and all apparatus use in this experiment are available in UMP lab such as Bend saw cutting machine, milling machine, Mahr Perthometer S2, Tachometer, 2D Microscope, Weight Balance and Surface grinding machine.

3.2 PREPARATION OF NANOCOOLANTS

There are two steps in preparation of nanocoolant that is:

1) Single-step direct evaporation method: In this method, the direct evaporation and condensation of the nanoparticulate materials in the base liquid are obtained to produce stable nanofluids.

2) Two-step method: In this method, first the nanoparticles are obtained by different methods and then are dispersed into the base liquid.

In this experiment, the second step of preparation of nanocoolant is used. Firstly the calculation is to be done because the SiO_2 that is in weight %. So, the value needs to convert to volume %. Eq. (3.1) is used to change the silica from weight % to volume %.

$$\theta = \frac{\omega \rho_{\mathrm{w}}}{\frac{\omega}{100}\rho_{\mathrm{w}} + \left(1 - \frac{\omega}{100}\right)\rho_{\mathrm{p}}} \tag{3.1}$$

where

When the volume in % is obtained, the further process to calculate how much the water need to dissolve the SiO_2 nanoparticle to get the right 5 % of water based SiO_2 nanoparticle. The equation used is as in Eq. (3.2)

$$\Delta V = V_1\left(\frac{\theta_1}{\theta_2} - 1\right) \tag{3.2}$$

where,

3.3 WORKPIECE PREPARATION

In this experiment, the material used is cast iron. The material is obtained from the foundry lab at UMP in raw material conditions. The raw material is been machining to get the dimensions according to the specifications needs.

Workpiece specifications are as follows:

Type of material	: Cast iron
Dimensions	: (20×30×65) mm

When the material is already been squaring, the next move is to cut its piece by piece. There is 9 sample of workpiece is needed. This ductile iron needs to cut by this bend saw due to its hardness and this machine also gives an accurate cut. Milling machine is used to squaring the raw shape of material. The process need to be done to get the dimensions of the workpiece. Figure 3.1 shows the milling machine that is used in this experiment. Figure 3.2 also shows the bend saw cutting machine.

Figure 3.1: Milling Machine

Figure 3.2: Bend Saw Cutting Machine

3.4 GRINDING PROCEDURE

In this experiment, the type of grinding use is surface grinding method. The parameter of the grinding will be set according to the Design of Experiment (DOE). The value of the parameter that is speed of table and depth of cut (DOC) will be used according to this DOE as shown in Table 3.1.

Table 3.1: Design of Experiment

Workpiece	**Table Speed (m/min)**	**Depth of Cut (μm)**	**Mass Different (g)**	**Diameter Different (mm)**	**Temperature Different (°c)**	**Time Taken (s)**
A	20	20				
B	20	20				
C	20	20				
D	30	40				
E	30	40				
F	30	40				
G	40	60				
H	40	60				
I	40	60				

There is two input parameter and its initial value for the experiment. There is 9 sample of test will be done. The desired value is the mass different, diameter different of grinding disk and temperature different. The time taken is based on the experimental grinding method. There is 2 types method of grinding is applied including single pass and multiple pass grinding technique. The single pass method will let the grinding disk feed the workpiece surface for a one feed only. For multiple pass the grinding disk will make contact with the surface of the workpiece for 10 times. The time will started when the machine is run and will stop counting when the pass grinding pass is finished for 1 strike for single pass and 10 strikes for multiple pass. Table 3.2 shows the time taken for each experiment. The time taken is based on the value of speed of table. The high value of speed table so less time was the grinding disk that made contact to the workpiece surface. This supposes to give the different result for material removal rate (MRR) and also for surface roughness effect on surface material. The experiment for each single and multiple pass were gone less than two set of grinding fluid that is conventional grinding fluid and also water based SiO_2 nanocoolant. This experiment will be conducted according to the DOE. Table 3.3 is listed the combination of experiments conducted.

Table 3.2: Time Taken for Each Experiment

Type of Experiment	Speed of Table (m/min)	Time Taken (s)
Single Pass	20	0.85
	30	0.64
	40	0.42
Multiple Pass	20	8.7
	30	6.5
	40	4.2

Table 3.3: List of Experiments

Types of Grinding Fluid	Grinding Technique	Abbreviation
Conventional Grinding Fluid	Single-pass	Conventional sp
Conventional Grinding Fluid	Multiple-pass	Conventional mp
Water Based SiO_2 Nanocoolant	Singe-pass	SiO_2 sp
Water Based SiO_2 Nanocoolant	Multiple-pass	SiO_2 mp

3.5 CENTRAL COMPOSITE DESIGN

This is the process to get the prediction model for the material removal rate (MRR) for each four types of experiment that been done. All the value regarding the experiment will used to gain this result. To get the value for MRR, the mass different of the workpiece before and after and also the time taken is used.

$$\text{MRR}= \frac{Mass\ different}{Time\ Taken} \tag{3.3}$$

From this information result, the value of these experiment will gather to get the prediction model of the MRR. All the equations and other interest vale related to its like analysis of varience (ANOVA) and lack of fits will be use togather in order to get the finest prediction model of MRR.Table 3.4 shows the design of central composite method. The minus (-) sign and the lowercase (*a*) sign indicate the value of minimum of the parameter. The positive (+) sign and capital letter (*A*) indicate the value of maximum paramater. The zero (0) is indicate the value of the middle of the parameter value.

Table 3.4 Central composite design method

No	Pattern	Speed of Table (m/min)	Depth of Cut (μm)	MRR (g/s)
1	--	20	20	0.179
2	*a*0	20	40	0.362
3	-+	20	60	0.533
4	0*a*	30	20	0.230
5	00	30	40	0.472
6	00	30	40	0.400
7	0*A*	30	60	0.698
8	+-	40	20	0.329
9	*A*0	40	40	0.698
10	++	40	60	1.131

3.6 G-RATIO

G-ratio value is the value of material removal rate (MRR) and the value of the tool wear. This value is need to study about the workpiece material and the grinding wheel. This value is shown the interaction between the MRR and the tool wear. The higher the value of G-ratio the better the method of grinding it is. To get the value of G-ratio is by using Eq. (3.4).

$$\text{G-ratio} = \frac{\text{Material Removal Rate}}{\text{Tool Wear}} \tag{3.4}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter contains the information of result from experimental and modeling based on response surface method. The mathematical modeling for conventional and nanocoolant are developed. The significance and adequacy of these models are verified by analysis of variance using the response surface method. The accuracy of the RSM model is studied. Moreover, this chapter depicts the optimal settings in order to achieve the optimum machining performance.

4.2 EXPERIMENTAL RESULTS

There are four types of experiments have been performed on grinding ductile iron using conventional grinding fluid and water based SiO_2 nanocoolant with single-pass (sp) and multiple-pass (mp) grinding technique. The results for various combination of grinding processes and different cooling fluids are presented in Table 4.1 – Table 4.4. The analysis is based on the material removal rate (MRR), G-Ratio, and surface roughness (SR). This result gives the experimental value to obtain for each desired parameter. The relationship between the parameter grinding is single pass and multiple pass grinding technique. The result may vary from each of technique and the use of different grinding fluid that is conventional grinding fluid and nanocoolant SiO_2 water based will give the different result. The analysis is based on the material removal rate, G-Ratio, and surface roughness.

Table 4.1: Experimental result for conventional single pass

Workpiece	Table Speed (m/min)	Depth of Cut (μm)	Mass Different (g)	Diameter Different (mm)	Temperature Different (^{o}c)	Time Taken (s)
A	20	20	0.152	0.05	1	0.85
B	20	20	0.308	0.05	1	0.85
C	20	20	0.453	0.10	1	0.85
D	30	40	0.147	0.05	1	0.64
E	30	40	0.302	0.10	1	0.64
F	30	40	0.447	0.10	1	0.64
G	40	60	0.138	0.10	2	0.42
H	40	60	0.293	0.15	2	0.42
I	40	60	0.475	0.20	3	0.42

Table 4.2: Experimental result for conventional multiple pass

Workpiece	Table Speed (m/min)	Depth of Cut (μm)	Mass Different (g)	Diameter Different (mm)	Temperature Different (^{o}c)	Time Taken (s)
A	20	20	0.204	0.15	1	8.7
B	20	20	0.354	0.10	1	8.7
C	20	20	0.512	0.15	1	8.7
D	30	40	0.196	0.15	2	6.5
E	30	40	0.347	0.20	2	6.5
F	30	40	0.498	0.25	3	6.5
G	40	60	0.192	0.30	3	4.2
H	40	60	0.342	0.35	3	4.2
I	40	60	0.487	0.45	4	4.2

Table 4.3: Experimental result for SiO_2 single pass

Workpiece	Table Speed (m/min)	Depth of Cut (μm)	Mass Different (g)	Diameter Different (mm)	Temperature Different (^{o}c)	Time Taken (s)
A	20	20	0.062	0.005	0	0.85
B	20	20	0.146	0.005	0	0.85
C	20	20	0.281	0.010	1	0.85
D	30	40	0.062	0.005	1	0.64
E	30	40	0.023	0.005	0	0.64
F	30	40	0.270	0.005	0	0.64
G	40	60	0.229	0.005	0	0.42
H	40	60	0.011	0.005	0	0.42
I	40	60	0.178	0.010	1	0.42

Table 4.4: Experimental result for SiO_2 multiple pass

Workpiece	Table Speed (m/min)	Depth of Cut (µm)	Mass Different (g)	Diameter Different (mm)	Temperature Different (^{o}c)	Time Taken (s)
A	20	20	0.071	0.005	1	8.7
B	20	20	0.228	0.010	0	8.7
C	20	20	0.473	0.025	0	8.7
D	30	40	0.210	0.085	1	6.5
E	30	40	0.263	0.095	0	6.5
F	30	40	0.114	0.085	0	6.5
G	40	60	0.361	0.005	0	4.2
H	40	60	0.304	0.070	0	4.2
I	40	60	10.208	0.005	1	4.2

4.3 MODELLING OF MATERIAL REMOVAL RATE

4.3.1 Analysis of Variance

Table 4.5 and 4.6 give the summary of the analysis of variance for conventional and SiO2 nanocoolant experiment. It can beseen that the P-value of lack of fit is more than 0.05 for all cases. Therefore, the models are adequate and fir for the further analysis.

From the sumarry value of the analysis, the result shows how the prediction model of MRR will be performed. This statistical result tell that the conventional experiment give the better prediction for MRR prediction model. The experiment with conventional single pass shows the value of p-value for model that is 0.0012 and for lack of fit is 0.3501. For conventional multiple pass the p-value for model is 0.0002 and for lack of fit is 0.2023. The F-static value is indicate where there is higher the value of F-static when there is significant effect in the model. The RSq value indicate how the correlation between the actual and the predicted model. Value of 1 refer to the perfect fit and 0 value mean that the fit predict the response no better than the overall response mean. For SiO_2 experiment, both give unexpexted value. The value for SiO_2 single pass of P-value for model is 0.5489 and for lack of fit is 0.0144. For SiO_2 multiple pass, the P-value for model is 0.0002 and lack of fit is 0.2023.

Table 4.5: ANOVA result for conventional coolant

Source	Degree of Freedom	Sum of Equation	F-static	P-Value	RSq
Single pass					
Model	3	0.65427360	22.4481	0.0012	
Error	6	0.05829200			
C.Total	9	0.71256560			
Lack of Fit	5	0.05570000	4.2978	0.3501	0.92
Pure Error	1	0.00259200			
Total Error	6	0.05829200			
Multiple pass					
Model	3	0.65427360	41.8410	0.0002	
Error	6	0.05829200			
C.Total	9	0.71256560			
Lack of Fit	5	0.05570000	13.5556	0.2023	0.95
Pure Error	1	0.00259200			
Total Error	6	0.05829200			

Table 4.6: ANOVA results for SiO_2 nanocoolant

Source	Degree of Freedom	Sum of Equation	F-static	P-Value
Single Pass				
Model	3	0.09689698	0.7755	0.5489
Error	6	0.24990942		
C.Total	9	0.34680640		
Lack of Fit	5	0.24989142	2776.571	0.0144
Pure Error	1	0.00001800		
Total Error	6	0.24990942		
Multiple Pass				
Model	3	0.65427360	41.8410	0.0002
Error	6	0.05829200		
C.Total	9	0.71256560		
Lack of Fit	5	0.05570000	13.5556	0.2023
Pure Error	1	0.00259200		
Total Error	6	0.05829200		

4.3.2 Mathematical Modeling

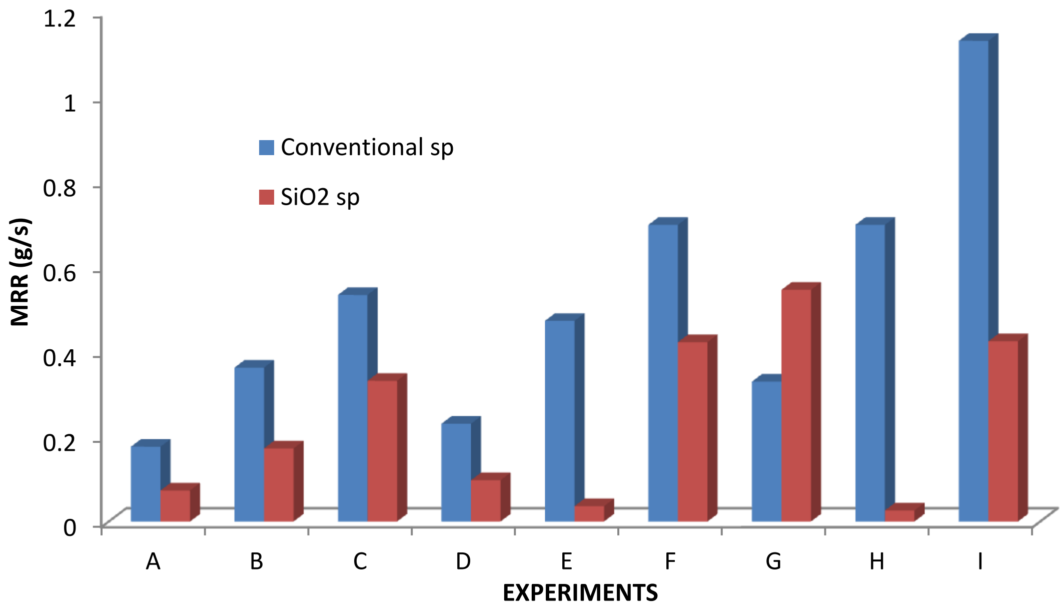
The data that gathered from the experiment will be use to develop the prediction model for material removal rate (MRR). The experiment that will be choose is conventional with single pass (conventional sp), conventional with multiple pass (conventional mp) and SiO_2 nanocoolant with single pass (SiO_2 sp). The experiment with SiO_2 nanocoolant with multiple pass will not be use for prediction of MRR model.The prediction model is used to obtained the theoretical value of MRR of the grinding process. The mathematical model for conventional and SiO_2 nanocoolant with single pass and multiple pass grinding pattern are expressed as Eq. (4.1)-Eq. (4.4).

$$\begin{aligned} MRR_{\mathrm{Conv\,single pass}} &= 541333.241986111 + 0.18099999999997 \times \mathrm{TS} + \\ &270666.666659722 \times \mathrm{DOC} + \mathrm{TS} \times TS\,(0.8866666666166) \end{aligned} \tag{4.1}$$

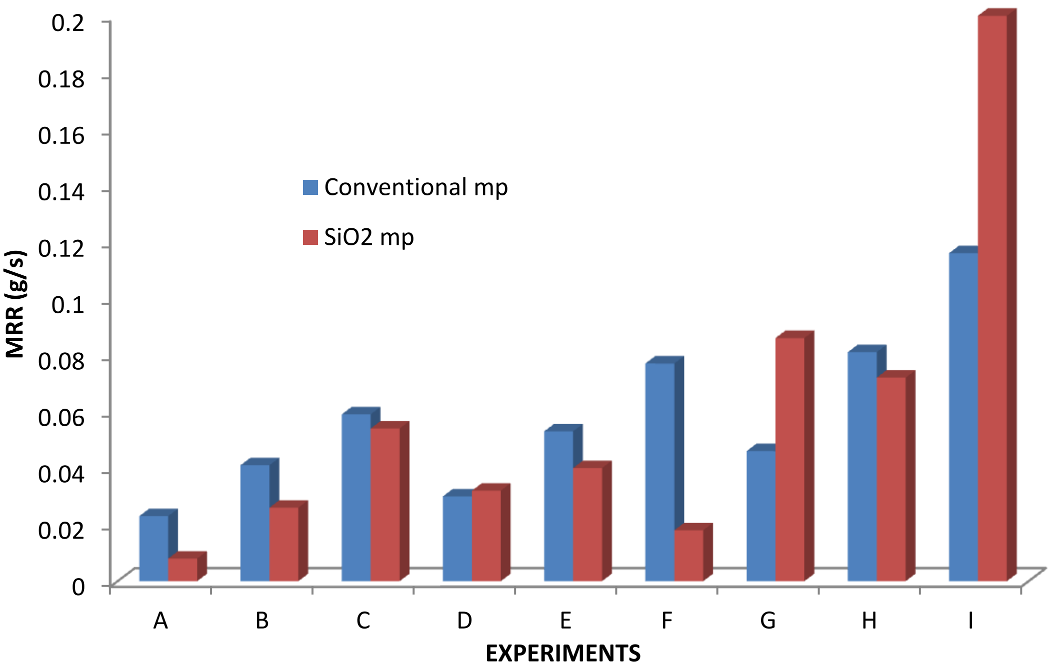
$$\begin{aligned} MRR_{\mathrm{Conv.multiple pass}} &= 1000.0014986075 + 0.02 \times \mathrm{TS} \\ &+ 25499.9999993037 \times DOC + \mathrm{TS} \times \mathrm{DOC}\,(0.00849999999953) \end{aligned} \tag{4.2}$$

$$\begin{aligned} MRR_{\mathrm{SiO_2\ single pass}} &= 153999.992266006 + 0.06983333333333 \times \mathrm{TS} + \\ &77000.0000080029 \times \mathrm{DOC} + \mathrm{TS} \times \mathrm{TS}\,(0.11558333333191) \end{aligned} \tag{4.3}$$

Table 4.7 shows comparison between the experimental and prediction value of the MRR for conventional and SiO2 nanocoolant. It is shown that the small different from all experiment is with conventional multiple pass grinding. Figure 4.1 shows the material removal rate for conventional and SiO2 nanocoolant with single and multiple pass grinding. It can be seen that the predicted value are similar to experimental results. This prediction model can be used for the purpose to get the prediction value for MRR. The volume of material of removal rate is the parameter that tells how much the material is removing by time. In this experiment, the value of the MRR is calculated with the unit of g/s. The value of the MRR is prefer to be high. It is shown that the conventional coolant gives the higher value of MRR that SiO_2 nanocoolant as a grinding fluid.



(a) Single pass grinding

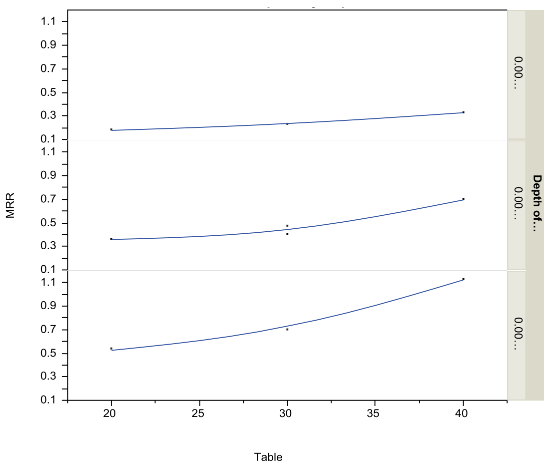


(b) Multiple pass

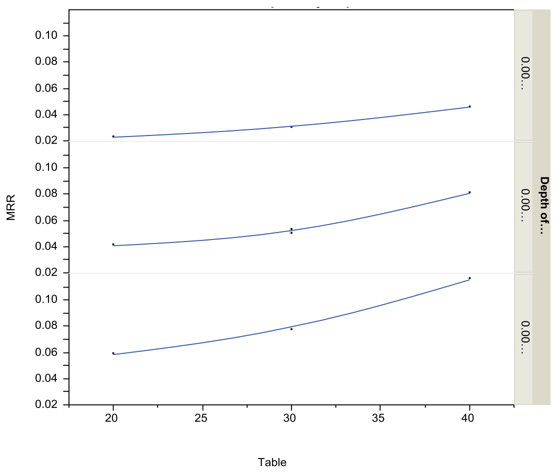
Figure 4.1: Material removal rate for conventional and SiO_2 nanocoolant with single and multiple pass grinding

Table 4.7: MRR for conventional and SiO_2 nanocoolant

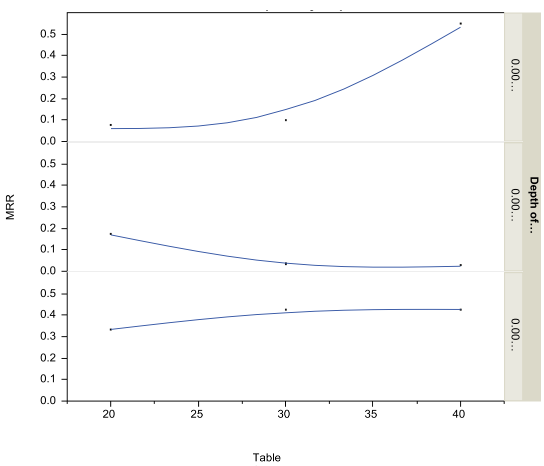
Workpiece	TS (m/min)	DOC (μm)	Conventional single pass	Conventional multiple pass	SiO_2 sp	SiO_2 mp
A	20	20	0.176	0.023	0.073	0.008
B	20	40	0.362	0.041	0.172	0.026
C	20	60	0.533	0.059	0.331	0.054
D	30	20	0.230	0.030	0.097	0.032
E	30	40	0.472	0.053	0.036	0.040
F	30	60	0.698	0.077	0.422	0.018
G	40	20	0.329	0.046	0.545	0.086
H	40	40	0.698	0.081	0.026	0.072
I	40	60	1.131	0.116	0.424	2.430



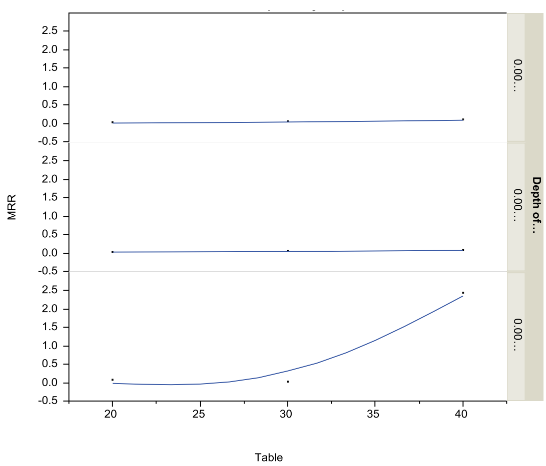
(a) Conventional coolant single pass



(b) Conventional coolant multiple pass



(a) SiO_2 nanocoolant single pass



(b) SiO_2 nanocoolant multiple pass

Figure 4.2: Variation of MRR vs table speed for different depth of cut

Figure 4.2 shows the interaction between speed of table and depth of cut (DOC) that influenced the material removal rate for conventional coolant and SiO2 nanocoolant with single and multiple pass grinding. It can be seen that the increasing of speed of table and DOC makes the MRR higher for all cases. The result shows that with speed of table of 20 m/min, the highest value for MRR is 0.059 with the DOC of 60 µm while the lowest is with the DOC of 20 µm is 0.023. For the speed of table of 30 m/min, the highest value of MRR is 0.077 that is with the DOC of 60 µm and the lowest value is with the DOC of 20 µm that is 0.030. The last is with the value of speed of table of 40 m/min, the highest vale for MRR is 0.116 that is with the DOC of 60 µm and the lowest value is 0.046 that is with the DOC of 20 µm. The result tells that the DOC and the speed of table give the influences to the MRR value. It is shown the high value of both parameter that is speed of table and DOC give the high value of MRR.

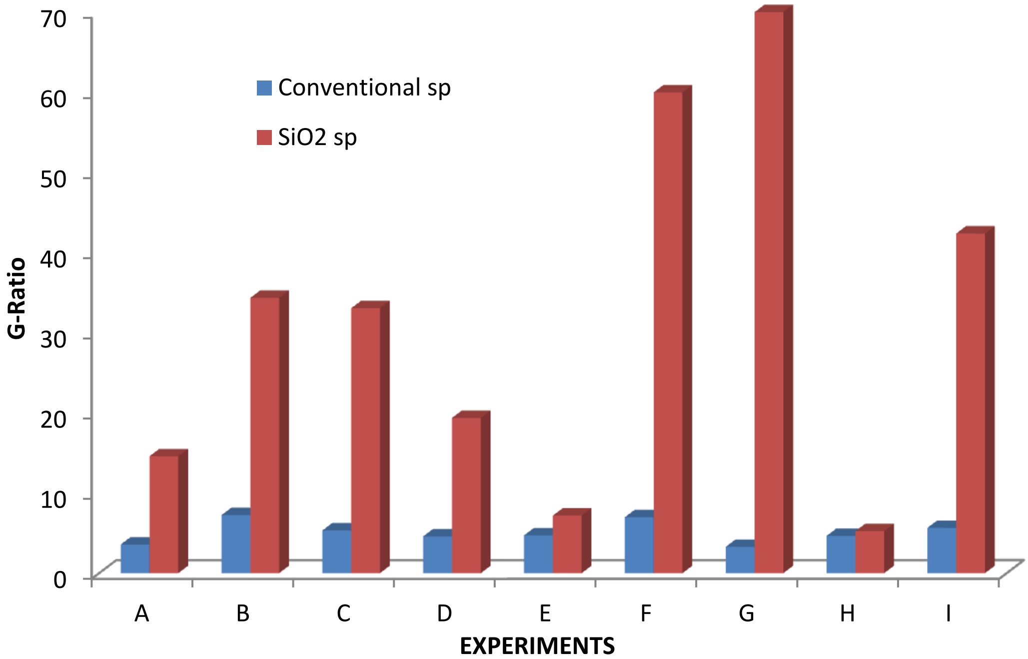
4.5 G-RATIO ANALYSIS

Table 4.8 shows the G-ratio value for conventional coolant and SiO_2 nanocoolant with single and multiple pass grinding. G-ratio is the parameter that describes the relationship between the material removal (MRR) and the tool wear (TW). The MRR is needed to be high and TW is needed to be low. The G-ratio will give the better information that tells what the best parameter needs to choose to get the better performance of grinding process. The G-ratio is the ratio between the MRR and TW. Accordingly, the higher value of G-ratio is better for the grinding process of parameter choice. The value of G-ratio is been influence by the MRR and TW value. Some of value seem too high, this is occur because of some defect may happen to the workpiece. Subsequently, the value of that result will also be discuss but when the data is converted into graph, the dummy value will be used so the graph will be easily to analyze and also easy to understand.

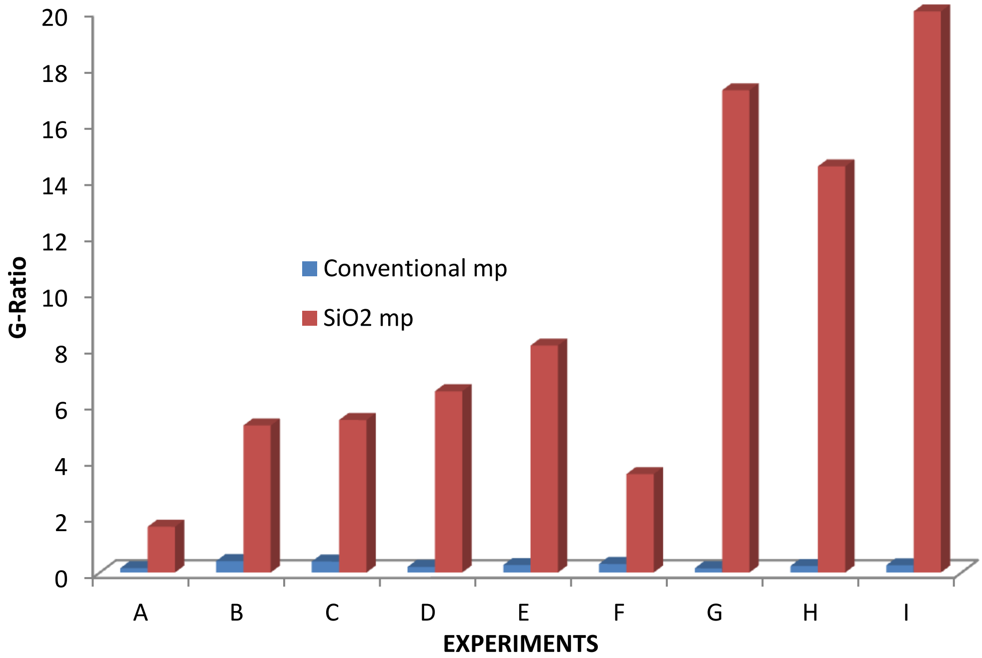
Table 4.8: G-ratio value for each experiment

Workpiece	TS (m/min)	DOC (µm)	G-Ratio			
			Conventional sp	Conventional mp	SiO2 sp	SiO2 Mp
A	20	20	3.576	0.156	14.588	1.632
B	20	40	7.247	0.407	34.353	5.241
C	20	60	5.329	0.392	33.059	5.437
D	30	20	4.594	0.201	19.375	6.462
E	30	40	4.719	0.267	7.188	8.092
F	30	60	6.984	0.306	84.375	3.508
G	40	20	3.286	0.152	109.048	17.190
H	40	40	4.651	0.233	5.238	14.476
I	40	60	5.655	0.258	42.381	243.048

Figure 4.3 shows the G-ratio value of conventional and nanocoolant grinding fluid with single and multiple pass grinding. It can be observed that the G-ratio is very much higher than conventional coolant. It is satisfy with the value of TW for nanocoolant grinding fluid is very low than conventional nanocoolant. The range is very high. Therefore, in term of G-ratio value, the nanocoolant grinding fluid is the best choice. This information also tell that the relationship between the MRR and TW. When the MRR and TW values are high, it gives the low G-ratio value however the MRR is high and the TW value low, the result will be show the high value of G-ratio. Thus, this parameter is important to improvise the value of parameter need to choose to get both qualities for MRR and TW value. The nanocoolant grinding fluid gives the better result for G-ratio value. Since the value of TW for nanocoolant grinding fluid is low it is give the result with the high value of G-ratio. Although the value of MRR for conventional grinding fluid is less than nanocoolant grinds fluid but in G-ratio term, the nanocoolant grinding gives the different result. It is shown that both of MRR and TW is the important parameter to be control in processing a surface grinding because it is related to the workpiece material and also the life of the tool.



(a) Single pass pattern

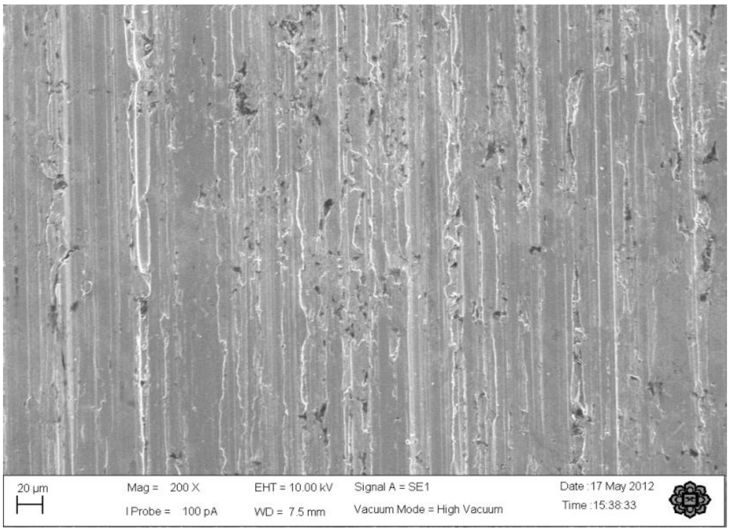


(b) Multiple pass pattern

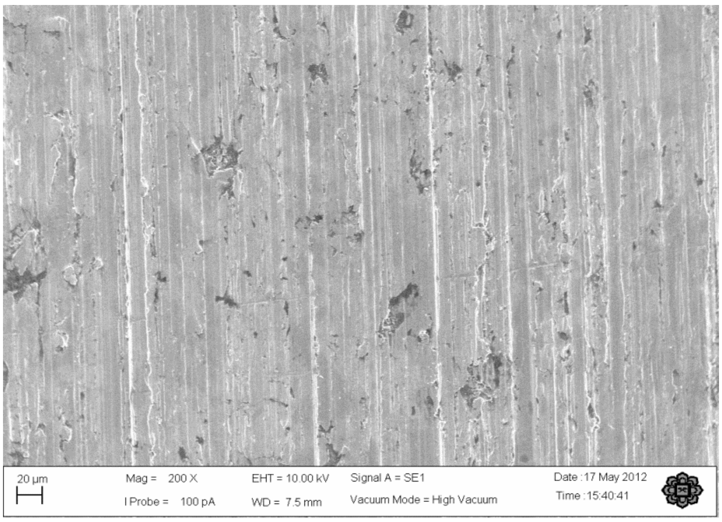
Figure 4.3: G-ratio value

4.6 SURFACE TOPOLOGY ANALYSIS

Figure 4.4 shows the surface topology for conventional and SiO_2 nanocoolant from the surface roughness analysis, the value of R_a is just slightly different from each experiment. Therefore, this method of scanning the surface of the workpiece can give the better proof that the surface of the workpiece is acceptable.



(a) Conventional grinding fluid



(b) Nanocoolant grinding fluid

Figure 4.4: Surface topology with magnification of 200x

Figure 4.5 shows the defect on the surface of the workpiece, with the magnificent of 700 times, the defect can be seen and this may be occurring as a result of the rough feed by the grinding disk. The depth of cut (DOC) of the grinding disk is given this kind of defect. This image is from one of the specimen with the DOC of 60 µm.

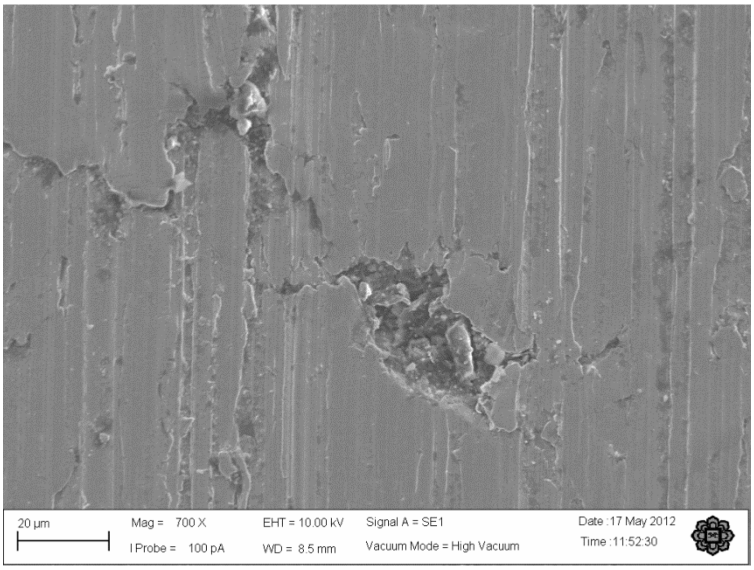


Figure 4.5: Defect on surface of the workpiece

4.7 THERMAL EFFECT

It is state that the element of thermal conductivity gives the effect of cooling for the grinding process. The different of temperature of the workpiece is using the different type of grinding fluid. The different of temperature can be seen from Table 4.9. It is observed that the different of the temperature for each experiment. The temperature different with water based SiO_2 nanocoolant gives the better performance than the conventional grinding fluid. This cooling effect gives less damage to the surface workpiece. The high temperature that occurs at the surface of the workpiece can damage the surface of the workpiece.

Table 4.9: The different of temperature for each experiment

Workpiece	**Temperature Different (^{o}c)**			
	Conventional sp	Conventional mp	SiO2 sp	SiO2 mp
A	1	1	0	1
B	1	1	0	0
C	1	1	1	0
D	1	2	1	1
E	1	2	0	0
F	1	3	0	0
G	2	3	0	0
H	2	3	0	0
I	3	4	1	1

CHAPTER 5

CONCLUSION

In this chapter, the conclusion will be made according to the objective of the project. It has been demonstrated that using the central composite design, the prediction model for MRR can be obtained. There are four types of experiment have been carried out. Conventional multiple pass gives prediction model is near to the experimental value. It can be seen that the prediction model can be used for other value of parameter since the stable and slightly different of value from the experimental and the prediction model. The prediction model that gives the best with using conventional grinding fluid by using multiple pass method of grinding. The results show that the grinding using the nanocoolant is gives the better result than the conventional grinding fluid. The nanocoolant performs well for four elements that are for surface roughness, tool wear, G-ratio. The result supposes occur because of the properties of the nanocoolant. Since the value of thermal conductivity is higher than the conventional grinding fluid, it provides better cooling effect and also gives the better condition for a grinding wheel.

For recommendation, there is another parameter can be use such as the speed of the grinding wheel. With the different type of parameter, suppose that the prediction model for the MRR will give the better result. The use of different type of nanocoolant also can give the different value for certain parameter such as the surface roughness.

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